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Learning Strategies and Individual Competence

G. Pask and B. C. E. Scott

System Research Limited, 2 Richmond Hill, Surrey, U.K.

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In a free-learning task, individuals are assigned to different categories of cognitive competence on the basis of the teaching strategy they adopt. Two major types are distinguished: *holists* or global learners and *serialists* or step by step learners, on the basis of analysis of the type of hypothesis that learners test in carrying out the task and a content analysis of the protocols produced when learners are asked to teach back what they have learned. For other tasks, using the same subjects, it is shown that teaching is most effective when the teaching materials are structured so as to match an individual's competence and the converse holds when there is mismatch. The results are interpreted for a theory of learning/teaching and the need for a language suitable for talking about strategies and subject matter structures is discussed.

1. Introduction

A student learns in a way that depends upon his individual cognitive style. It is less commonly recognized that differences of style have great educational importance because students fare very differently according to whether the teaching materials are or are not adapted to suit their idiosyncracies. Henceforward, a student's style or mental character is referred to as his cognitive *competence* which, as later, is a measurable individual property.

Likewise, teaching materials can be structured, via the tutorial strategy they embody, to fit one of 2 or 3 types of commonly observed competence. If the teaching materials are structured to suit the individual's competence (a "matched" condition), then learning is very much more effective than it is if the converse applies (a "mismatched" condition).

The experiments reported in this paper were concerned with establishing differences in competence, with setting up matched and mismatched conditions and comparing their influence upon learning, both at a molar and molecular level. In addition, a quantifiable "teachback" testing technique was introduced which, superficially at least, appears more defensible than multiple choice (or other readily scored) examination methods.

1.1 PRACTICAL APPLICATION OF THE RESULTS

The practical consequences of the (generally affirmative) results to be reported are as follows: (a) education could be rendered much more effective if students were assigned properly matched tutorial materials. (As it stands, most everyday materials, lectures, texts, teaching programmes, have a strong bias towards one or another type of student. Since they are presented indiscriminately to a mixed class any individual is likely to receive mismatched instruction.); (b) the "proper" design principles can be clearly specified and are neither hard to instrument nor counter-intuitive; (c) 2 or 3 types of individual difference in competence can be quite easily detected, as a result of which the "matching" requirement is entirely realistic; and (d) conventional multiple choice examinations could be profitably replaced by teach-back testing (which would, incidentally, provide *one* source of the data needed to establish a student's competence).

1.2 OUTLINE OF PROCEDURES

Quite simple tests, which may either be manually or automatically administered, are shown to distinguish between two major categories of mental competence which reflect an individual's cognitive style and lead him, in free learning conditions, to prefer a certain type of strategy, i.e. to direct his attention in a specific way to different parts of a learning task, to ask specific sorts of questions, to assimilate material by specific types of "self explanation" and to pose specific sorts of hypotheses.

The two major categories of individual are called *serialists* and *holists*. This distinction was first made in the context of a relation learning task (Pask, 1969*a*; Pask & Scott, 1971) but it has been found equally germane in connection with intellectual tasks.

Serialists learn, remember and recapitulate a body of information in terms of string-like cognitive structures where items are related by simple data links: formally, by "low order relations". Since serialists habitually assimilate lengthy sequences of data, they are intolerant of irrelevant information unless, as individuals, they are equipped with an unusually large memory capacity. Holists, on the other hand, learn, remember and recapitulate as a whole: formally, in terms of "high order relations".

There are two subcategories of holist called *irredundant holists* and *redundant holists*. Students of both types image an entire system of facts or principles. Though an irredundant holist's image is rightly interconnected, it contains only relevant and essential constituents. In contrast, redundant holists entertain images that contain *logically* irrelevant or overspecific material, commonly derived from data used to "enrich" the curriculum, and these students embed the salient facts and principles in a network of redundant items. Though *logically* irrelevant, the items in question are of great psychological importance to a "redundant holist", since he uses them to access, retain and manipulate whatever he was originally required to learn.

The categories of competence (serial, holistic) are quite commonsensical and would be evident to many experienced teachers. Our innovation is twofold.

(1) Although the categories could be empirically adduced, it is also possible to predict their existence on the basis of a theory of learning and teaching; the prediction is logically exact and unambiguous. The theory is described in Pask, 1965, 1968, 1969*b*,*c*, 1970*a*,*b*, 1971.*

(2) Due to the clearcut distinction existing at a theoretical level, it is possible to specify simple testing methods for determining an individual's type of competence and (as later) to show that these methods are effective.

For experimental purposes, an individual's competence was determined under "free learning" or "browsing" conditions by a questioning and goal selecting procedure that led him to externalize his mental process as an observable stretch of behaviour.

The free learning technique (Section 2) has the following general properties. Prior to free learning the subject is introduced to the task goal (learning a zoological taxonomy) and reads through an introductory and irredundant description of the system. Now the taxonomic system and its universe of discourse can be redundantly described by five categories of statements which are inscribed on cards placed in separate piles according to their category. The student learns by "questioning", i.e. by turning up cards and (if he wishes) generating new "cards" via note taking. He is given a limited period in which to work but he is free to ask any question provided that he states a *reason* for doing so. The "questions" asked, the reasons for asking them and the notes taken (and counted as "fresh cards") are all recorded. As anticipated from preliminary studies, the reasons could all be summarized under one of the following headings:

(i) to "search a co-ordinate of the message space", i.e. to pass through a pack of cards as though thumbing over the pages of one chapter in a book; (ii) to "search for a datum regarding a particular object, specimen, fact, etc., named independently of the card-category co-ordinates";

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*The full theory is presented in later papers in the series submitted to this journal, notably Pask, G. and Scott, B. C. E. "CASTE: a system for exhibiting learning strategies and regulating uncertainty" and Pask, G. "A theory of conversations and individuals".

(iii) to "test an hypothesis about a simple predicate" (for example, that a specimen in Class X has more than two legs); (iv) to "test an hypothesis about a complex predicate" (for example, that Class X differs from Class Y in respect of leg number *and* mating behaviour *or* habitat).

The serialist differs from the holist chiefly in terms of the complexity (order) of predicates involved in the hypotheses he tests. A redundant holist differs from an irredundant holist in terms of his question distribution amongst the card-category co-ordinates. Success and failure in a subsequent test are correlated with the ratio of the number of hypotheses testing questions to the number of searching questions uttered during free learning (a better correlation seems to exist between success and the *logical* information content of the hypothesis testing questions.)

The tenure of the competence type assigned on the basis of a student's free learning characteristics was checked by a simple content analysis of the dialogue during an interview-like or tutorial procedure in which each student "taught back" to the experimenter whatever he had learned.

The analysis extracts (amongst other things) the proportion of inferential and hypothetical statements uttered during teachback and the value of this quantity discriminates between serialists and holists. In all cases, this molecular teachback data yielded exactly the same competence assignment as the molecular free learning data.

It is also true that either method of competence assignment (free learning, teachback) may be "automated" for use in a C.A.I. system. Experimenter administration, though convenient and entirely practicable, is not mandatory. For, once the data base is fixed, the administration follows an algorithm.

Finally, there is some evidence that a competence type can be reliably assigned on the basis of a simple content analysis of essays or other written materials that are freely composed by the student in question.

Thus "competence determination" might be practically accomplished by any one of the following methods.

(a) Questioning and selecting during free learning—(human administration).

(b) Questioning and selecting during free learning—(machine administration).

(c) Content analysis of essays (for example, using the categories outlined by Schneidmann (1966)).

(d) Tutorial (teachback) procedure—(human administration).

(e) Tutorial (teachback) procedure—(machine administration).

Any piece of educational material, a textbook, a course module or a teaching programme, is based upon a teaching strategy. The teaching strategy is analagous to the learning strategy used by a student to direct his attention during free learning except that it is imposed by the teacher or course designer rather than generated by the student himself.

Teaching strategies can be slanted to suit an individual with a given sort of competence. For example, a teaching strategy can be designed with a serialist in mind, or a holist.

The theory prescribes quite accurately, what *sort* of teaching strategy *will* suit a given type of individual. When speaking of "serialist materials" and "holist materials" in the sequel we mean materials structured according to these principles.

Since human beings are highly adaptable it may be possible for an individual with *any* sort of competence to learn, in the end, according to any teaching strategy. But the experiments show, very clearly indeed, that the rate, quality and durability of learning is crucially dependent upon whether or not the teaching strategy is of a sort that suits the individual. The "matched" and "mismatched" conditions were compared as shown in Fig. 1.

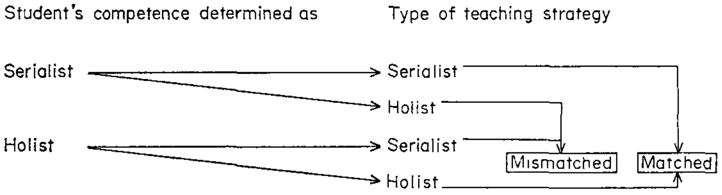


FIG. 1. Comparisons made.

Whereas the matched students learned effectively (near perfectly) the mismatched students did not do so (and retained hardly any ungarbled knowledge). This assertion is based on molar data; the test results of section 2 where the appropriate comparisons yield differences significant at the 0·1% level for groups of $N = 8$ each. The differences evident on examining the molecular data, which indicate why the distinction exists, are even greater.

The skeleton of the experimental design is shown in Fig. 2. The treatment takes place over two experimental sessions [(I) and (II)] separated by about two weeks, during which two similar tasks were used (both of them "learning a taxonomy of unfamiliar objects", called "Martian Fauna"). The content of each task is roughly one lesson's worth; Task 1 corresponds to a medium-sized (approx. $\frac{1}{2}$ hr) lesson and Task 2 corresponds to a long (approx. 1 hr) lesson.

The first session (I) establishes the competence of an individual student; as a result he is assigned, on the second session (II) to a matched or a mismatched group. The *tests* are conventionally marked 30-item questionnaires tapping factual knowledge (about 80 %) and ability to generalize (about 20 %).

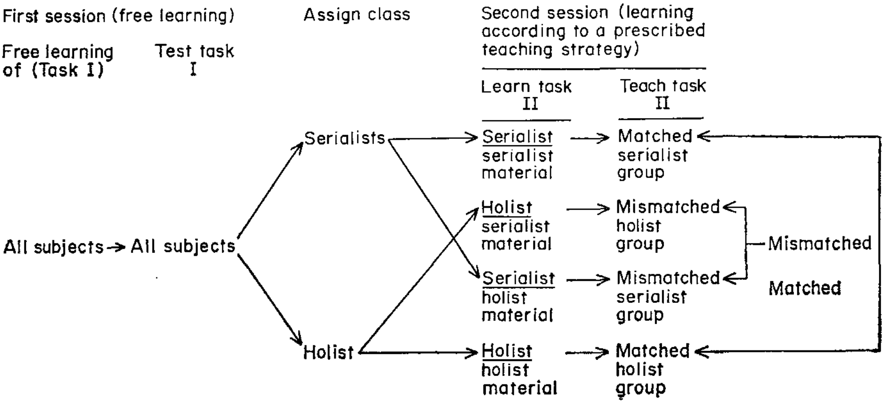

First session (free learning)
Free learning of (Task I)
Test task I
Assign class
Second session (learning according to a prescribed teaching strategy)
Learn task II
Teach task II
All subjects
All subjects
Serialists
Holist
Serialist serialist material
Holist serialist material
Serialist holist material
Holist holist material
Matched serialist group
Mismatched holist group
Mismatched serialist group
Matched holist group
Mismatched
Matched

FIG. 2. Outline design.

The design was embellished to test the further hypothesis, that an ability to retain complex information over an appreciable period depends upon a cognitive process of reconstruction (which may be likened to the reproduction or self-explanation of the concept in question). At first sight, the "concept reproduction" hypothesis has no obvious connection with the initial hypothesis about matching cognitive competence to a teaching strategy. But it does, in fact, stem from the same theory, though it was developed somewhat later (actually, during the early part of the experimental work).

The practical consequence is as follows. If the "concept reproduction" hypothesis is true, then the conventional test scoring methods of examination are unlikely to discriminate between students who *have* and have *not* learned a concept. Rather than taking an examination, students should show evidence that they can reproduce the required concept in a conversational (or quasi-conversational) interaction with a tutor (or computer program) during which the concept reproducing process can be externalized for observation as the student "teaches back" the concept he has allegedly learned.

It is true that the act of doing so is likely to teach *him* the concept in its own right and to this extent it is impossible to separate testing and teaching. For educational purposes, the confusion is unimportant; after all, the object of education is to *teach* somehow. But it does mean that an experiment can only discriminate the subsequent retention of students who have demonstrated an ability to teachback with the retention of students who have been subjected to a comparable experience ("ineffective teachback") in which part of the reconstructive cycle is deliberately omitted.

After free learning Task (I) all students were subjected to one or other version (a) or (b) of a teachback procedure.

Half of them were randomly assigned to a real teachback (unqualified teachback) defined thus:

(a) the student is asked to teach the experimenter how to use the taxonomy on the assumption that the experimenter is a person of the same mental make-up as the student himself but is omniscient with respect to all *relevant* aspects of the task (i.e. *to all items that appear in the test and all items, derivable from the irredundant introduction introduction that might appear in the test*). On completing the teachback any mistakes or omissions are corrected and the student is asked to reconstruct his teachback so that they are eliminated. The cycle of *correction* and *reconstruction* is repeated until no errors or omissions remain in the teachback.

Half of the students were randomly assigned to an ineffective teachback (b) defined thus:

(b) the student is asked to teach the experimenter how to use the taxonomy on the assumption that the experimenter is a person of the same mental make-up as the student himself but is *omniscient* with respect to all *relevant* aspects of the task. On completing the teachback any mistakes or omissions are noted and the student is furnished with knowledge of results that corrects each mistake (or omission) *and* states *why* the response was mistaken or how an omission is related to the body of the taxonomy. The student is now *tested* over omitted or mistaken items (he is *not* required to teachback again) and knowledge of results is furnished with respect to each mistaken test response. The cycle of *correction* and *testing* is continued until no errors or omissions remain.

After learning Task (II) (taught by a matched or a mismatched teaching programme) all students were subjected to a further teachback routine. In this case, the object is not to establish a distinction between "Teachback" and "Ineffective Teachback". Rather, as already noted, molecular teachback data is employed to check the competence assignment and, in addition, to elucidate the influence of matched and mismatched instruction upon a student's mental organization. Consequently (i) only the first cycle of the teachback process is recorded and (ii) the underlined relevance criterion of the previous account is replaced by "the experimenter is a person of the same make-up as the student but is omniscient with respect to all relevant aspects of the task, i.e. *all items that appeared in the teaching programme*".

The modified experimental design, obtained by incorporating the teach-back conditions, is shown in Fig. 3.

1.3 GENERALIZATION OF THE MAIN RESULT

One reasonable criticism of the pilot experiment is that the initial and the criterial tasks are (necessarily) of the same type and thus that the match/mismatch paradigm may be restricted to just one sort of subject matter. Though valid, the criticism is unavoidable for an experiment of this magnitude.

To blunt its force, further experiments were carried out using some of the original, competence-assigned, subjects who learned a very different task under conditions of match and mismatch. These subjects had to learn and manipulate the biochemical concept of an "operon", as proposed by Monod & Jacob. A successful student must become familiar with the operation of two coupled feedback cycles, which are complicated by a double negation; in the subsystem of repressor, corepressor, and aporepressor.

Due to time pressure, only the molar data has been recorded and the result (that matched subjects fare well on a *different* type of task whereas mismatched subjects fare badly) should be taken as no more than suggestively affirmative. It is true that the gross score differences (section 2) are *signifiant* but, in the absence of molecular data obtained in the main experiment, we cannot be sure of the mental mechanism involved and thus have less confidence in the finding.

1.4 CHANGE OF STRATEGY

A further criticism is that the students involved in the experiment did not change their strategy in the course of learning. The effect of strategy change is unobtrusive, partly because the learning time is relatively short and partly because the task structure is homogeneous and chosen so that it can be learned with roughly equal facility by a serialist and a holist. The *one* subject who did change his strategy was excluded from the group in order to avoid complicating the analysis and the data record.

In general, strategy change is neither uncommon nor unexpected. This aspect of the learning process has not, so far, been explored in the context of intellectual skills, but a respectable body of data is available from relation learning tasks (Pask & Lewis, 1968; Pask, 1969*a*, 1970*a*; Pask & Scott, 1969, 1971) and similar mechanisms may operate in the present field.

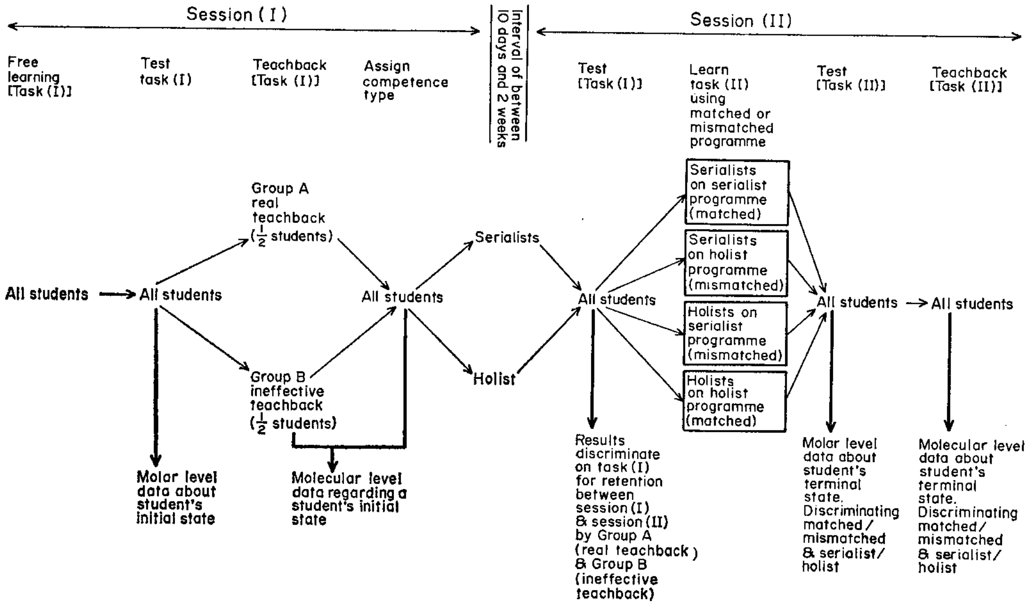

Session (I)
Interval of between 10 days and 2 weeks
Session (II)
Free learning [Task (I)]
Test task (I)
Teachback [Task (I)]
Assign competence type
Test [Task (I)]
Learn task (II) using matched or mismatched programme
Test [Task (II)]
Teachback [Task (II)]
All students
All students
Group A real teachback (½ students)
Group B ineffective teachback (½ students)
Molar level data about student's initial state
Molecular level data regarding a student's initial state
All students
Serialists
Holist
All students
Results discriminate on task (I) for retention between session (I) & session (II) by Group A (real teachback) & Group B (ineffective teachback)
Serialists on serialist programme (matched)
Serialists on holist programme (mismatched)
Holists on serialist programme (mismatched)
Holists on holist programme (matched)
All students
Molar level data about student's terminal state. Discriminating matched/mismatched & serialist/holist
All students
Molecular level data about student's terminal state. Discriminating matched/mismatched & serialist/holist

FIG. 3. Final design.

1.5 TEACHBACK AND FREE LEARNING AS DISCOURSE IN A TASK SPECIFIC METALANGUAGE

Both the free learning (selection and questioning) technique and the teachback technique provide the skeleton for a *language*, logically a *metalanguage*, in terms of which the student can externalize and discuss the way in which he learns. In each case we started out with only a broad idea of what sorts of utterance the student would make, allowing him to use natural language expressions in order to say whatever he liked, provided it was relevant to the task. However, as anticipated, students did not use an unlimited number of statement types and the statements they *did* make obeyed rather obvious rules. It thus appears that the dialogue, either in teachback or free learning, can be formalized without detriment. Formalization may be of two sorts: (a) a systematic questioning "language", for use in connection with humanly administered free learning and teachback situations; or (b) formalization as an on line quasi-conversational "language" for use in CAI systems or in computer aided testing. Although the syntax required by (a) and (b) is somewhat different, the semantic structures underlying (a) and (b) are virtually identical.

So far as taxonomy learning is concerned, the humanly administered language for the free learning situation [(a) of section 1.5] is already substantially formalized. Only a suitable notation is required. By token of this the content analysis, of section 2, tacitly assumes a formal scheme, and, the learning strategy graphs referred to in section 2 are tantamount to expressions (or classes of expressions) in the questioning language for taxonomy tasks. Inspection of these graphs should convince the reader that a thoroughgoing "formalization" is a practicable proposition in *this* subject matter area. Much the same comments seem to be true in the field of *process* or *system* learning touched upon in the auxiliary experiments of section 1.3. But, here, for the reasons already given, we are unable to substantiate our belief by molecular data.

1.6 A GENERAL QUESTIONING LANGUAGE

It is not unreasonable to propose a questioning language [either in the sense of (a) or (b) of section 1.5] which is general enough to adumbrate many subject matter areas of academic and technical interest; for example, large parts of chemistry, biology, and the other sciences; most of the abstract disciplines and some parts of history and the social sciences. The potential utility of a general questioning language as a tutorial adjunct is demonstrated by the present study, but it has an equally cogent application as a vehicle for representing subject matter structure.

1.7 INFORMATION MEASURES. A THEORETICAL SPECULATION

If a language is given, then it is sensible to contemplate an information measure over expressions in the language and the universe to which they refer. If such a measure were available it could be used to compare two or more learning situations, for instance, in terms of their relative difficulty.

The following points merit emphasis: (a) the currency of a language does not *guarantee* that a satisfactory measure *can* be imposed; (b) a satisfactory information measure would be akin to a *logical* or *semantic* measure in the sense of Cherry, Bar Hillel, Carnap, Ciaraviglio & Siegman, that is, the content of an expression is related to the set of inferences it enables or prohibits. It is not a statistical information measure based upon occurrence probabilities (in the more usual sense of Ashby, Garner, McGill & Shannon).

1.8 CATEGORIES

The categories delineated in this paper, though useful, are not believed to be exhaustive. For example, it is well worth examining other classifications such as Bruner's (1967) between visual and verbal thinking; Guildfords (1966) classification; and the various cognitive styles considered by Kagan (1963), Witkin (1962) and others.

2. Experimental Work

2.1 PRELIMINARY WORK AND PREPARATION OF THE LEARNING TASKS

Given an outline of the experimental design in Fig. 3. it was first necessary to choose an appropriate task.

Certain task requirements are mandatory.

(1) Learning should occupy about 1 hr for the criterial task [Task (II)] and somewhat less for the initial task [Task (I)] (i.e. a short enough time to be experimentally tractable and a long enough time (a) to be realistic and (b) to let the student externalize a sensible stretch of mental activity).

(2) The criterial and initial tasks should be similar according to any reasonable cannons.

(3) It should be possible to learn according to a serialist or a holist strategy so that both kinds of strategy *can* be employed and so that a student's disposition, manifest during free learning, may be taken to indicate his competence.

In addition, it is desirable to satisfy the further conditions listed overleaf.

(4) As well as being learnable by either strategy, the task should neither be biassed in favour of a serialist or a holist teaching strategy. The intention is to compare serialist/holist students or matched/mismatched students, and not to examine the appropriateness of one approach or the other to the task in hand. Hence, an attempt was made to secure no significant difference between the mean scores, on the criterial task (II), of the serialist and the holist groups.

(5) To avoid spurious individual differences, the material to be learned should not be much more familiar to one student than another.

To satisfy the requirements (1–5) an extensive series of tests were carried out using materials culled from Upton & Sampson's (1963) "Creative Analysis". Each item used for this purpose took between 5 and 10 min to learn and five separate items were examined; learning the meaning of a written passage, learning a map of the Carribean, learning a taxonomy, learning analogies and learning the operation of an abstract system. Each subject's learning process was examined by recording his recall and by informal discussion. It transpired that all of the materials chosen satisfied conditions (1), (2), (3) and (5) and taxonomy learning or, with some minor qualifications system learning were likely to satisfy condition (4).

The brief test items from "Creative Analysis" are not long enough to serve, as they stand, for experimental tasks, so four appropriate and lengthy batches of task material were constructed at this stage, and pre-tested for general suitability. The first two of them underlie Task (I) and Task (II) of the main experiment. They are two separate universes of discourse with redundantly specified descriptive properties. The objects in the universe of discourse are variously related "Martian Fauna" called [in Task (I)] "Clobbits" and [in Task (II)] "Gandlemullers". In each case a task is generated by defining a taxonomy or classification scheme, the tests in which refer to a subset of the descriptive properties (so called "physical variables") and by requiring the student to learn (and learn to use) the taxonomy in question. These tasks are detailed in section 2.2.

The remaining two batches of material involve systems.

One is the biochemical system controlled by an "Operon" (in the sense of Jacob & Monod, 1971) as exemplified by the regulation of lactose-glucose-metabolism. The system to be learned involves two major interactive feedback loops; the notions of inducer, repressor, corepressor and aporepressor; the (underdeveloped) notion of enzymes as specific proteins that catalyse the transformation of metabolites and the tacit but deliberately suppressed concept of the messenger RNA–Ribosome–transfer RNA chain that is responsible for synthesizing enzymes under the basic instructions written onto the DNA configuration of the structural genes.

The other batch of material concerns the human menstrual cycle and the "underdeveloped" concept of its interruption by fertilization and pregnancy. This system involves the following basic notions: the endometrium as a growing (and later decaying) tissue controlled by oestrogen and progesterone; the ovary as a source of ova developing in their follicles via an independent growth process; the lutenization of a graffian follicle; the ovarian constituents (graffian follicle and corpus luteum) as the most relevant source of the regulating hormones (oestrogen, progesterone) and the existence of other sources (e.g. placenta, in pregnancy); the pituitary as a source of the ovary regulating hormones (follicle stimulating, lutenizing, and prolactin); the notion of feedback from oestrogen–progesterone levels to regulate the output of the pituitary hormones; the notion of overriding hypothallamic control of the feedback from oestrogen–progesterone levels to regulate the output of the pituitary and the notion of direct feedback to the hypothalamus.

With the caveats and suppressions noted, members of the target population are substantially ignorant of the systemic details to be learned and do not entertain gross misconceptions about what actually goes on. They do, of course, have a broad background knowledge (so that terms like "DNA" or "ovary" or "endometrium" have meaning to them). This knowledge allows them to erect complex associational references (which is an advantage in studying the behaviour of a redundant holist) but it is of no great help to *them* in elucidating the system dynamics.

Due to time limitations only one of these batches, the "operon" system, was employed as a learning task in the present enquiry and this one formed the background of the *auxiliary* study.

2.2 TASKS USED IN THE MAIN EXPERIMENT

Task (I) was to learn the "clobbits" taxonomy. It is noteworthy that any zoological taxonomy (and, in practice, many other sorts of taxonomy also), can be learned and manipulated in various ways. For example, though a novice is *instructed* to use the classification rules in an orderly fashion, the expert unashamedly *recognizes* the member of a species by diverse, though relevant, criteria, This possibility comes about because the relations between subspecies are multiple (perhaps infinite) and can be expressed free of the taxonomy; because there are relations of symmetry, assymetry, complementation, etc. *within* the given taxonomic tree; and because there are many alternative ways of making a pertinent distinction between subspecies. For example, the subspecies might be distinguished in terms of the physical variables which generally (and, in this case certainly) are tested in the taxonomy itself; by differences in the behaviour of the animals concerned or by contextual information; for instance, regarding the habitat of the animals or the historical origins of the classifying nomenclature. We stress that this degree of richness *is* and is *known* to be embodied in our Tasks. Learning one of them is not simply an arid and abstract exercise.

In Task (I) there are 10 subspecies of "Clobbit" with two main subtypes, "Clobs" and "Bits". There are 9 test boxes or branches in the classification tree (Fig. 4) and 7 physical characteristics are tested to make the requisite distinctions. For parts of the taxonomy, the values of *other* physical characteristics discriminate the classes equally well. The structure contains symmetries (for example, four 4-legged Bits and four 3-legged Bits); it also contains assymmetries (for example, the 4-legged Bits are first assigned to two subspecies yielding one and three subspecies (by leg position); the 3-legged Bits are assigned by leg position to two subsets each containing two subspecies. Some of the names of the animals are assigned rationally (T stands for Triped; K stands for legs at corners, but since TK is used only for 3-legged creatures the suffix TK is *redundant*). Some names have no rational justification. There is background information about the behaviour and habitat of the clobbits, some of which is relevant to the distinctions made (and might be used to make them *redundant*) and some of which is irrelevant.

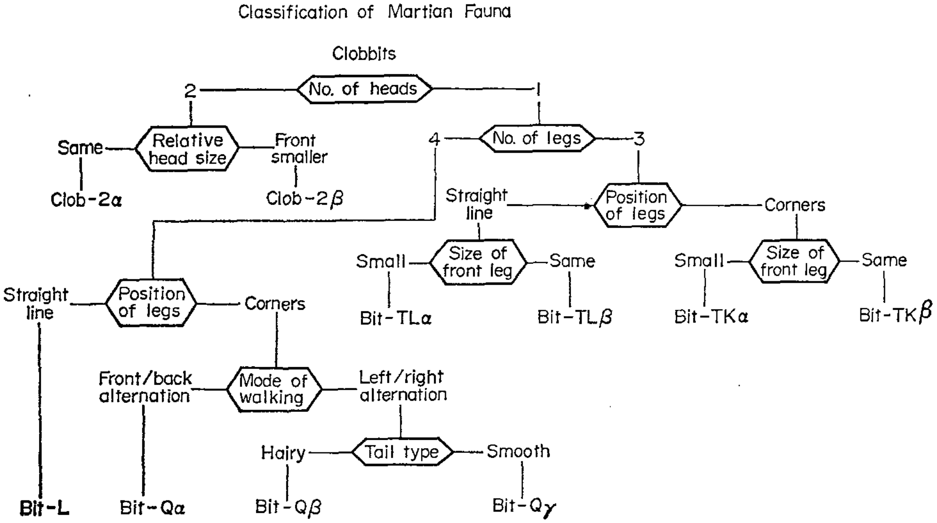


FIG. 4. Clobbit taxonomy.

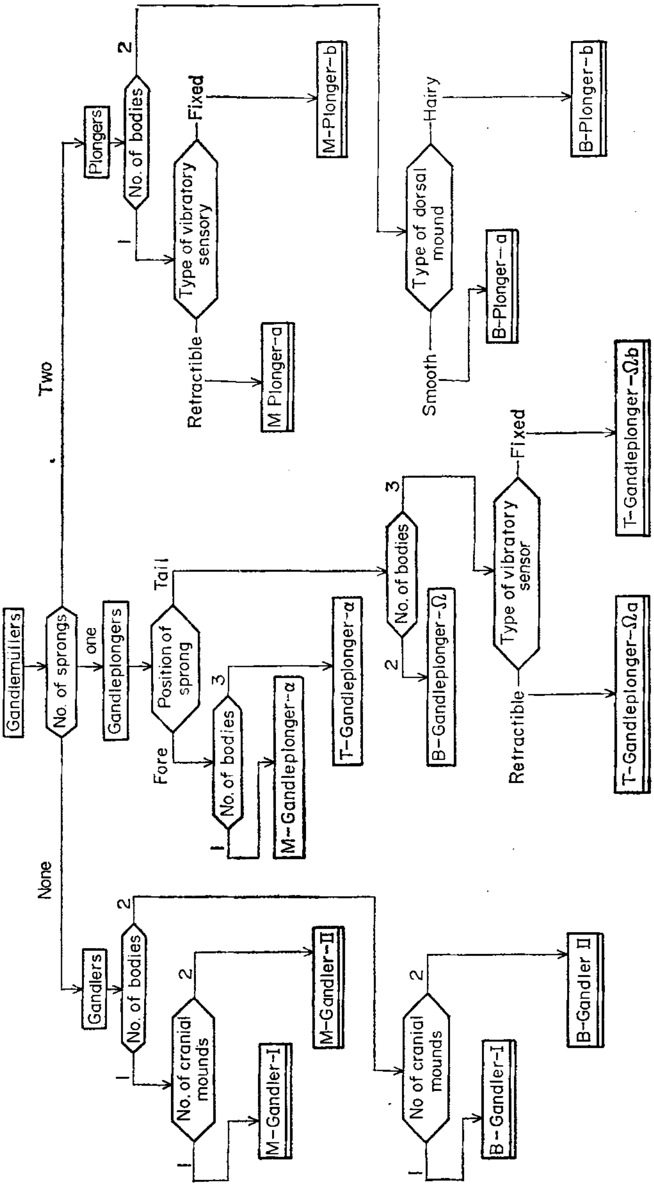


FIG. 5. Gandlemuller taxonomy.

Finally, each subspecies of Clobbit is associated with a picture of one member of it.

In Task (II) students learn a taxonomy of "Gandlemullers" of which there are 13 subspecies and three main subtypes. The classification tree (Fig. 5) has 11 "tests" or branch points entailing six physical characteristics. All of the general comments made about the "Clobbits" apply equally to the "Gandlemullers".

2.3 SUBJECTS

The 16 subjects used in the main experiment were aged between 18 and 24. None of them had taken part in the preliminary experiments (section 2.1). They were drawn from various student populations, most of them coming from Kingston College of Technology. Eight of the subjects were serialists and eight of them holists.

The balanced 8/8 sample is not altogether fortuitous and should not be taken to reflect on even distribution of serialists and holists in the population. Although the first subjects were recruited "randomly", the remainder were selected with foreknowledge of their personality and occupation, to obtain serialists or holists as required. It is possible to infer a subject competence's quite accurately from this information. The authors can both do so, though, we have only the most general concept of the cues we employ for this purpose. In fact, the following subjects were non-randomly selected and their competence types accurately predicted.

(a) *Serialists.* 2 electrical engineering students engaged on programming 1 mathematics graduate, 1 economics graduate and 1 physics graduate.

(b) *Holists.* 1 philosophy graduate currently working in social psychology, 1 physics graduate studying operational research, 2 sociology undergraduates.

2.4 SESSION (I). FREE LEARNING AND DESCRIPTION OF THE TASK (I) UNIVERSE

Information about the (free learning) Task (I) universe is written on cards that belong to five classes A, B, C, D, E. On the front of each card is a statement which specifies the type of data to be found on its reverse (or face) side. The cards are arranged face downwards in a five-column array in which each column contains the members of one of the classes A, B, C, D, E. Every column is labelled to indicate the *class* of data written on any of the member cards, namely:

Class A	10 cards showing pictures of a typical member of a Clobbit subspecies;
Class B	13 cards giving contextual information about the appearance, habitat, or behaviour of these animals;
Class C	5 cards stating the structure of the taxonomy. Each card names the members of a subspecies and states the numbers of physical characteristics tested in order to distinguish this subspecies;
Class D	7 cards naming physical characteristics of the clobbits and the values assumed by each property on each of the subspecies which it is used to distinguish.
Class E	7 cards indicating the subspecies names or codes and why they were used.

Prior to free learning the student is oriented by reading through an introduction which states the goal and *all* of the strictly relevant information. After this he is allowed 25 min in which to ask questions. To ask a question the student selects one card at once, and turns it over to scrutinize the message on its face. During this process he knows (as noted in section 1.2) that the cards convey redundant information, i.e. that all the requisite data could be obtained from A and C; from A and D; from C, D, and E; or from B and certain subsets of the remaining cards in the array.

For each question (or, in the case of a coherent search, each sequence of questions) the student is required to give a reason for asking the question concerned and his reasons are tape-recorded. The time occupied in giving reasons is not deducted from the time allowed for questioning. As noted in section 1.2 only four sorts of reason were actually given (to recapitulate): (i) search a card class or co-ordinate of the message space; (ii) search for a specific datum; (iii) test a single predicate hypothesis; (iv) test a multiple predicate hypothesis.

Of these, the occurrence frequency of type (iv) reasons is used to discriminate serialist and holist competence, for which purpose it is unnecessary to enquire *what* hypothesis is being tested. In general (for example, for the questioning languages of section 1.5 and 1.6) it would be necessary to delineate the hypotheses; but they are readily specified within the framework afforded by the array and the four categories of reasons for questioning.

It is predictable, from the theory, that holist mentation will be discriminated from serialist mentation by the occurrence, in free learning or in teachback of tests for hypotheses based on complex predicates rather than simple ones. Due to the unitary nature of the tests in the classification tree a simple predicate hypothesis is probably a single predicate hypothesis and, given this identification, the discrimination is clearcut. Table 1, is the "analysis of reasons" on which the initial assignment of competence type was based.

A more comprehensive picture of free learning is given by the four typical learning strategy graphs of Appendix 1. Each of the main nodes represents a note made by the student. The transitions between nodes represent the order in which the student elected to ask questions and the transitions are coded to depict his reasons for doing so.

TABLE 1

Molecular data from free learning session (1). *Competence type assignment based on type* (*of predicate*) *in hypothesis*

		Information seeking transitions	"Small" predicate in hypotheses	"Large" predicate in hypotheses
Serialist	1	19	3	0
	3	10	7	0
	4	37	0	0
	6	20	0	0
	8	9	9	0
	10	26	6	0
	12	18	1	0
	16	18	5	0
Holist	2	10	8	8
	5	21	2	13
	7	22	8	5
	9	8	2	14
	11	8	2	10
	13	7	5	9
	14	11	0	8
	15	20	0	5

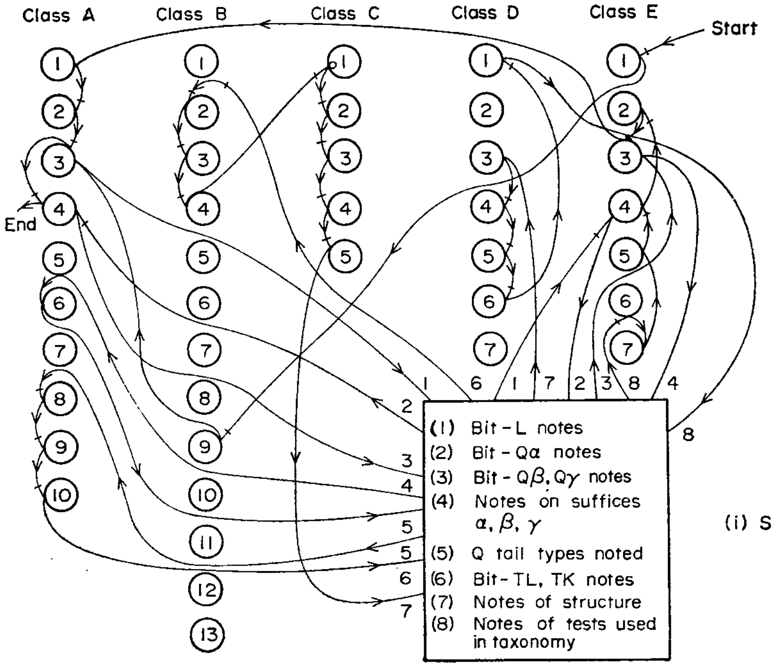
APPENDIX 1

Typical Learning Strategy Graphs

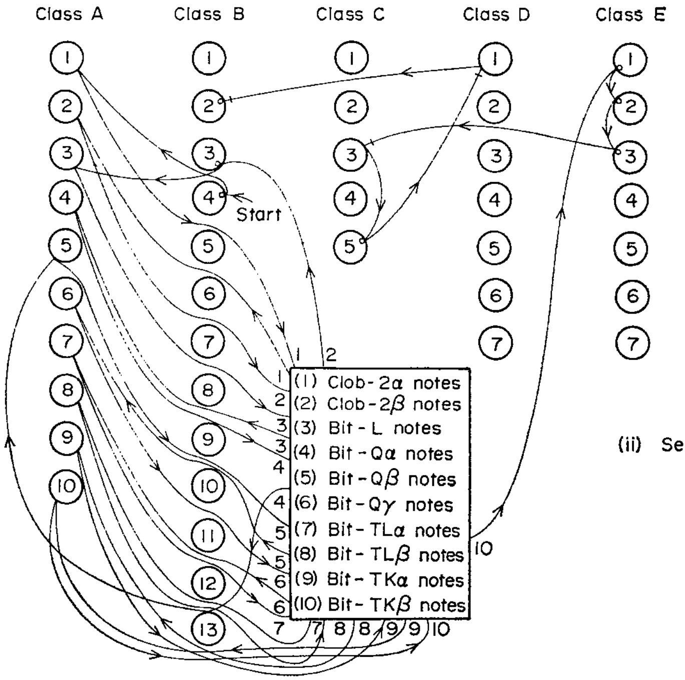
(i) and (ii) serialist students
(iii) redundant holist
(iv) irredundant holist

KEY

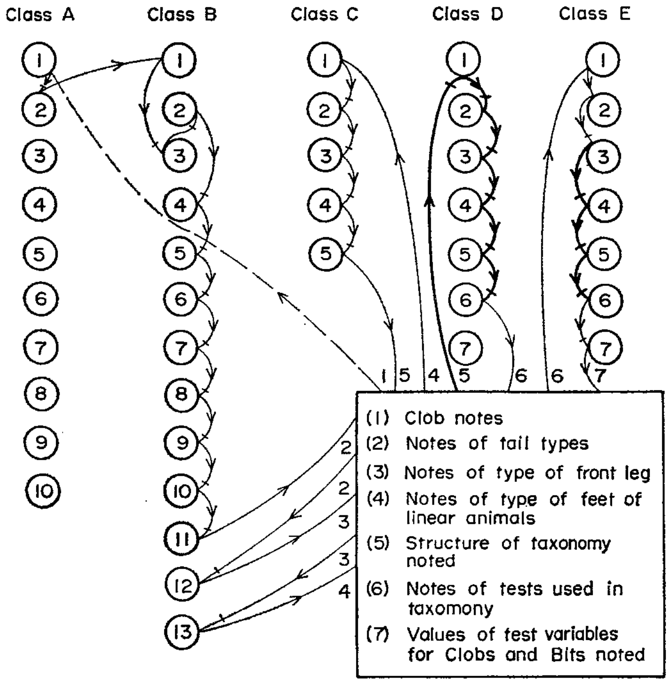
Class A	pictures of typical members of subspecies.
Class B	contextual information (behaviour, habitat, etc.)
Class C	statements about structure of taxonomy.
Class D	physical characteristics used for making distinctions between subspecies.
Class E	Meaning of subspecies names and codes.
ⓝ	Card *n* of a particular column of the array.
———	= General search.
▬▬▬	= Testing many predicate hypothesis.
- - - -	= Testing single predicate hypothesis.
↘○	= Failure to find information sought after.
↘○	= Transition between questions.



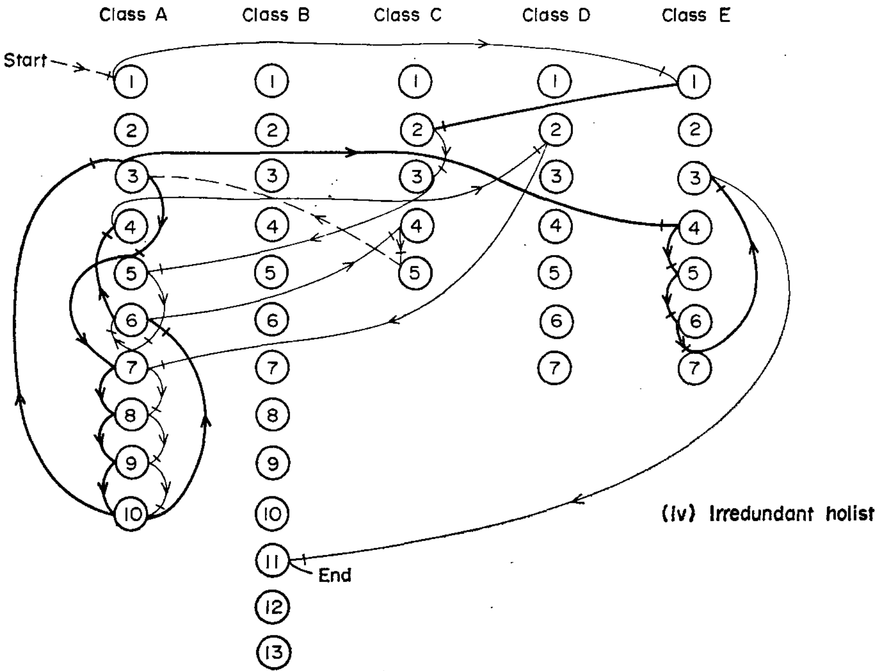
(i) Serialist



(ii) Serialist


Class A
Class B
Class C
Class D
Class E
(1) Clob notes
(2) Notes of tail types
(3) Notes of type of front leg
(4) Notes of type of feet of linear animals
(5) Structure of taxonomy noted
(6) Notes of tests used in taxomony
(7) Values of test variables for Clobs and Bits noted

(iii) Redundant holist



(iv) Irredundant holist

By way of a summary, the competence types are associated with the following behaviour patterns.

(a) *An Irredundant Holist* [Subject (iv) of Appendix 1] sets out to find the overall form of the classification tree and to locate its tests; typically he garners this data from classes B, D, or E. He sets up (usually complex predicate) hypotheses about the values of the physical characteristics of each subspecies and tests them by inspecting picture cards in Set A.

(b) *A Redundant Holist* [Subject (iii) of Appendix 1] scans through cards of many or all classes. He bases complex hypotheses mostly on the subspecies names or codes of Set E cards (for example, that some creature is 3-legged and 1-headed and has a short front leg and has a bushy tail) and tests them by inspecting cards in Set A.

Holists, either *irredundant* or *redundant* commit mistakes due to simple over-generalization (for example, that (β) always implies "Bushy Tail" which is true for only *some* subspecies) or systemic over-generalization to render the classification *scheme* more rational or symmetrical than it actually is (for example, falsely naming a subspecies "Bit QL" on the evidence that Q stands for "4-legged" and L stands for "Linear" together with the valid inference that a 4-legged linear creature exists).

(c) *A Serialist* [Subject (i) and subject (ii) of Appendix 1] is prone to list the

TABLE 2
Molar data

Subject		Clobbit [Task (I)] Test			Gandlemuller (Task [II)] test		
Number		1st session (max 30)	2nd session (max 30)	2nd and 1st score difference	Task II test	Student type	Programme type
TB	1	13	30	+	9	S	H
TB	2	25	27	+	21	H	S
	3	25	17	−	29	S	S
TB	4	10	28	+	7	S	H
	5	27	23	−	30	H	H
	6	15	10	−	9	S	H
TB	7	27	30	+	30	H	H
	8	27	18	−	28	S	S
TB	9	28	30	+	30	H	H
	10	17	13	−	30	S	S
	11	23	19	−	19	H	S
TB	12	18	30	+	9	S	H
	13	21	25	+	30	H	H
	14	26	17	−	16	H	S
TB	15	21	28	+	20	H	S
	16	22	17	−	29	S	S

subspecies by examining picture cards in Class A. If he is to be successful, he checks the relevance of the information entering his list by forming single predicate hypotheses (for example, that a BIT L has 4 legs) and testing them by inspection of the cards in set D or C. A structure is thus built up in orderly stages.

Serialists fall into difficulties if they fail to distinguish the wood from the trees and consequently try to assimilate masses of sparsely related irrelevant information. The most marked manifestation of this failing is an attempt to list all features of the picture cards in Class A. But, even if relevance is determined systematically, the serialist strategy appears to impose an appreciable load on storage capability. Some students who accumulated *all* the relevant data failed, subsequently, to *reconstruct* the entire taxonomy.

As noted in section 1.2, the test administered after free learning the initial task was a 30-item questionnaire. The test scores are shown in Table 2.

2.5 SESSION (II). PROCEDURES

Achievement at Task (I) was again tested at the beginning of Session (II). The test scores are shown in Table 2.

Task (II) is to learn the taxonomy of Fig. 5 on the universe discussed in section 2.2. This universe is also redundantly described by a set of cards. These were used to generate the serialist and holist teaching programmes employed for instructing Task (II). Both of the programmes convey exactly the same *strictly relevant* information, knowledge of which is *subsequently tested.* Both of the programmes have a linear presentational format (the serialist programme has 11 information and test frames and the holist programme has 25 information and test frames). But the concepts they instruct are different and very differently structured. Segments of both programmes are shown in Appendix 2.

APPENDIX 2

Training Programmes for Session (II)

(i) *Segment of serialist training programme*

Frame 1

(a) Zoologists, during recent surveys of Mars, have classified a species of fauna, the GANDLEMULLER, into a series of subspecies on the basis of physical characteristics.

(b) Zoologists have classified the .... on the basis of.......... ....

Frame 2

(a) There are three main subspecies; GANDLERS, PLONGERS and GANDLEPLONGERS. They are distinguished from each other by the number and position of SPRONGS (horny spikes).

(b) The horny spikes used as distinguishing characteristics are called........... Their number and position distinguishes .... the three main subspecies, from each other.

Frame 3

(a) GANDLERS have *no* sprongs..
PLONGERS have *two* sprongs (fore and tail).
GANDLEPLONGERS have *one* sprong (fore or tail).

(b) GANDLERS have ...... sprongs, ... have either a tail or fore sprong, ... have both a tail and a fore sprong.

Frame 4

(a) There are four subdivisions of the subspecies GANDLER: M-GANDLER-I; M-GANDLER-II; B-GANDLER-I; B-GANDLER-II. They are distinguished from each other by the number of bodies (one or two) and the type of cranial mould (single or double).

(b) The four GANDLER subspecies have prefix........ or .... and suffix .... or ....
GANDLERS have one or two ....
GANDLERS have a .... or .... cranial mound.

Frame 5

(a) M-GANDLERS I and II have one body. B-GANDLERS I and II have two bodies. M-GANDLER-I and B-GANDLER-I have a single cranial mound.
M-GANDLER-II and B-GANDLER-II have a double cranial mound.

(b) B-GANDLERS I and II have .... whereas M-GANDLERS I and II have .... and .... have a single cranial mound. .... and .... have a double cranial mound.

(ii) *Segment of holist training programme*

Frame 1

(a) In recent surveys of Mars, zoologists have classified a species of fauna, the GANDLEMULLER, into a series of 13 distinct subspecies on the basis of physical characteristics observed on laboratory specimens.

(b) Zoologists have classified the .... on the basis of ....

Frame 2

(a) Some subspecies differ with respect to more than one physical characteristic; there are, therefore, alternative ways of making distinctions. The GANDLEMULLER subspecies also exhibit differences in terms of behavioural habits.

(b) As well as differing in physical characteristics GANDLEMULLER subspecies also differ in terms of........... ....

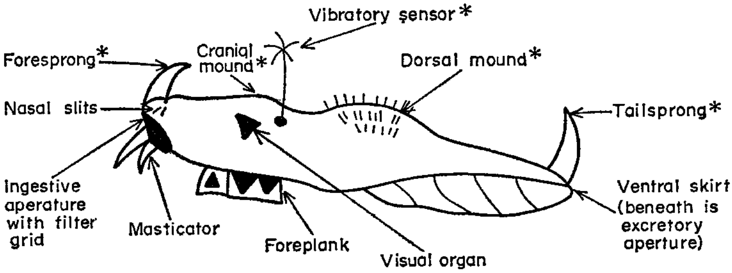
Frame 3

(a) The name "GANDLEMULLER" is formed from GANDLE (Martian for swamp–Mud) and MULLER (German for Miller), hence "swamp mud miller", since GANDLEMULLERS are found in the Martian swamp land of the equatorial regions. They inhabit mudflats and deep, dark damp caves. They are almost translucent and active only at night.

(b) GANDLE is Martian for ....
GANDLEMULLERS are active only during the ....

Frame 4

(a) *Typical adult Gandlemuller*



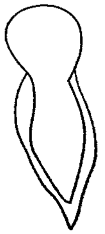
No. of bodies* (1, 2 or 3)

This is a picture of a typical adult GANDLEMULLER, approx. 2 ft. 6 in. in length. The picture shows names of physical characteristics. Those characteristics used in the standard classification are marked thus*.

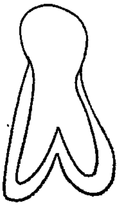
(b) The lump on the back of a GANDLEMULLER is called the .... The spike at the rear is called a ....

Frame 5

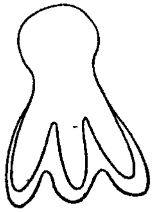
(a)



M type



B type



T type

Subspecies are found with one, two or three bodies. The bodies are joined laterally as in top views shown. A prefix to the subspecies name indicates the number of bodies: M(mono)=one body; B(bi)=two bodies; T(tri)=three bodies. Picture shows plan view.

(b) Prefix B indicates creature has ....

Prefix M is short for ....

Frame 6

(a) There are three main subspecies types: GANDLERS, PLONGERS and GANDLEPLONGERS. All three types have subspecies with one and two body forms. Only GANDLEPLONGERS have three body forms.

(b) The three main subspecies are .... and .... Only .... have three body forms.

Frame 7

(a) The standard classification distinguishes between the three main subspecies according to the number and position of SPRONGS (horny spikes). The commonest alternative classification (of Russian origin)—and the only alternative mentioned here—uses number and type of MASTICATOR (tongue-like organ) in place of SPRONG differences.

(b) The horny spikes used as distinguishing characteristics are called .... Their number and position distinguish ...., ..., and ...., the three main subspecies, from each other.

(c) The Russian classification uses .... number and type instead of number and position of spong as a distinguishing characteristic.

Frame 8

(a) SPRONGS, when worn, are used as a defence against predators, chiefly the OWZARD or Martian night vulture. MASTICATORS are used to propel mud into the ingestive aperture, through a grid-like filter which prevents large objects entering.

(b) Sprongs are a defence against the Martian night vulture or .... Masticators propel mud into the ....

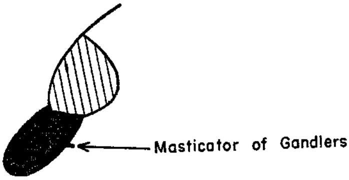
Frame 9

(a) Micro-organisms and proteinaceous materials are extracted from the mud ingested and stored in the dorsal mound for later digestion. The extraction of nutritive substances takes approx. 2½ min. The residue is excreted. As feeding lasts from 3–6 hr, ingestion and excretion are virtually simultaneous.

(b) Food materials are stored in the .... for later digestion.

Frame 10

(a) The name GANDLER is a corruption of the species name GANDLEMULLER. GANDLERS have no sprongs. They avoid OWZARDS by excreting all mud being processed, collapsing the FOREPLANK, and lying flat below the surface of the mud swamp. GANDLERS have a single masticator as in picture attached.



(b) GANDLERS have .... sprong(s)
GANDLERS have a .... masticator.
OWZARDS are avoided by collapsing the ...., excreting all mud and lying flat.

The holist programme is designed for a *redundant* holist and scrutiny of the Task (II) teachback data shows that it wholly defeats a serialist student. A programme designed for an *irredundant* holist might not have done so and thus might have given rise to a less marked distinction between the matched and the mismatched groups.

The decision to design the holist programme for a redundant holist was partly intended to facilitate this sort of result so that (if a real distinction was found to exist) it could be demonstrated clearly over a modestly sized group of subjects. But the decision is also realistic. A dichotomy does exist between two extreme sorts of educational material. On the one hand there are materials replete with "enrichment" and based also upon "overall" concepts which are well suited to the redundant holist. At the other extreme there are teaching algorithms, single step teaching programmes and the like which are suited to serialists. There is, in practice, rather little material "in between" or a sort that would be addressed to an irredundant holist.

The serialist programme refers to a kernal of strictly relevant concepts which are presented in an orderly and logical fashion. Inspection of the Task (II) teachback shows that it defeats a redundant holist and offers a difficult (and incidentally, unpalatable) learning experience to an irredundant holist, though students with this competence do eventually come to grips with it.

Both programmes were administered in the same way with the following instructions and criteria for advancement. Recall that both programmes are in a linear format, and thus consist in a series of information and test frames.

(1) At the *n*th frame, $n = 1$, the subject is asked to read slowly through the information frame (actually, a card of the sort used for questioning and answering during the free learning task).
(2) When the subject has finished, he is presented with a test frame (a card containing questions and blank spaces to fill in).
(3) If the subject responds correctly, he is presented with the $n+1$th information frame (unless the *n*th frame is the last, when step 6, below, is executed).
(4) If the response is mistaken, the *n*th information frame is presented and read once again.
(5) The cycle is repeated so that a subject does not advance to the $n+1$th frame until his response to the *n*th is correct in all particulars.
(6) On completion of the programme, the student either has or has not completed an error free run. If he has done so, the procedure terminates.
(7) If any error has been committed the entire programme is repeated until such moment as the criterion stated in stage 6 is satisfied.
(8) Since the procedure is cyclic, all students are eventually forced to complete one run of the programme to which they are assigned without any overt mistakes.

Let us emphasize that satisfaction of this criterion does not imply that a student has learned the taxonomy even though he gives the appearance of mastery and even though criteria of this type are often believed to indicate mastery is attained.

Next, a student's knowledge is tested by means of a 30-item questionnaire. The test scores obtained from holists and serialists who received instruction via a matched mode (holist/holist programme; serialist/serialist programme) or via a mismatched mode (holist/serialist programme; serialist/holist programme) are shown in Table 2.

The final event in Session (II) was the elicitation of "teachback" (section 1.2) the results of which were recorded and content analysed.

(i) To check the original competence classification, based on the free learning of Task (I) during Session (I).

(ii) To elucidate the processes involved in matched and mismatched learning.

Some typical "Teachback" protocols are set out in Appendix 3. The differences between students and the cognitive dilemmas they encountered are apparent from an inspection of this data. To quantify them, two sorts of analysis were conducted, the results of which are shown in Table 3 and Table 4.

APPENDIX 3

Typical Teachback Protocols for Task II

KEY

$n\rightarrow$ $\leftarrow n$	Information derived from frame *n*
▬▬▬▬	Inventions
————	Irrelevant information
…………	Redundant information
ıııııııııı	Statement referring to information to be presented or previously mentioned
∼∼∼∼	Information inferred from the programme by the subject.
════	A false statement.
+	Cross reference of a false statement with a correction.
[ ]	Repetitions.
( )	Other comments, interjections, etc.

(i) *Holist with holist programme*

(1) I'm going to tell you about a $^{1\rightarrow}$funny Martian animal which has been recently discovered and classified by scientists conducting surveys $^{\leftarrow 1}$. They are funny slug-like things with $^{1\rightarrow}$various protruberances, some of which, differ amongst the different types. Zoologists use these differences to draw up a classification $^{\leftarrow 1}$ $^{2\rightarrow}$There are other ways of telling them apart $^{\leftarrow 2}$ $^{7\rightarrow}$The main alternative is a Russian scheme which uses masticator differences where the standard scheme talks about sprongs $^{\leftarrow 7}$ $^{8\rightarrow}$which are a kind of horny spike, used for defence against predators, notably the Owzard or night vulture which is also Martian $^{\leftarrow 8}$

(2) $^{1\rightarrow}$These animals are called Gandlemullers, $^{\leftarrow 1}$ $^{3\rightarrow}$because they churn about in the swamps near the equator and Gandle is Martian for swampmud, hence smampmudmiller—muller is German for Miller $^{\leftarrow 3}$. [These things churn through the mud], $^{9\rightarrow}$eating it by some curious process which means they eat and exciete at the same time $^{\leftarrow 9}$—like a flow through bakery.

(3) [Anyway, they sit about eating this stuff] and all $^{18\rightarrow}$the time they wave tendrils in the air called vibratory sensors for detecting Owzard's wing beats $^{\leftarrow 18}$. When attacked, they do various things depending on their defence equipment. For a start $^{19\rightarrow}$some of them retract their sensors. Some don't because they are fixed $^{\leftarrow 19}$ $^{10\rightarrow}$Some of them lie all flat and squashed because they have no spikes for stabbing. $^{\leftarrow 10}$ Others have these sprong things and do various gymnastics. If $^{11\rightarrow}$they have a front and back spike they jackknife. $^{\leftarrow 11}$ If $^{13\rightarrow}$they have only a front one, they rear up on a thing at the back called a ventral skirt $^{\leftarrow 13}$. If $^{14\rightarrow}$their spike is at the back, they do it the other way on a thing called a foreplank $^{\leftarrow 14}$ which, by the way, $^{10\rightarrow}$is collapsed by the ones that have no sprongs so they can get flat $^{\leftarrow 10}$.

(4) Anyway, if we come to the classification proper you'll see how they differ in the various ways.

(5) (Now) $^{1\rightarrow}$There are 13 different subspecies $^{\leftarrow 1}$ $^{6\rightarrow}$divided into 3 main types. There are $^{15\leftarrow}$4 Gandlers, $^{\rightarrow 15}$ $^{18\rightarrow}$4 Plongers $^{\leftarrow 18}$ and $^{23\rightarrow}$5 Gandleplongers $^{\leftarrow 6}$, ^{23}.

(6) You $^{5\leftarrow}$get these with various numbers of bodies—one, two or three and a subspecies has a prefix M(mono), B(bi), T (tri) to say which is which $^{\rightarrow 5}$.

(7) There $^{15\rightarrow}$are 2 M-Gandlers, 2B-Gandlers. $^{\leftarrow 15}$. Similarly there $^{18\rightarrow}$are 2 M-Plongers and 2 B-Plongers $^{\leftarrow 18}$.

(8) Now $^{5\rightarrow}$in Gandleplongers you get the T-types $^{\leftarrow 5}$ Oh, $^{12\rightarrow}$there are 2 sorts of Gandleplonger called $^{13\rightarrow}$α or Ω. $^{14\rightarrow}$depending on their spong. You see they have only one sprong $^{\leftarrow 12}$. α is the one with it at the front $^{\leftarrow 13}$ and Ω is at the rear $^{\leftarrow 14}$. They're the ones that pivot at the front or back depending, as I said before. Anyway, $^{23\rightarrow}$there are 2 α's an M and a T and there are 3 Ω's, one B and two T's $^{\leftarrow 23}$. I'll say how you tell them apart in a minute, but first I must say about sprongs.

(9) $^{10\rightarrow}$Gandlers are the ones with no sprongs $^{\leftarrow 10}$ $^{11\rightarrow}$Plongers are the ones with 2 sprongs $^{\leftarrow 11}$ and $^{12\rightarrow}$[Gandleplongers have one at the front or back $^{\leftarrow 12}$, as I just said$^{13\rightarrow}$α and $^{14\rightarrow}$Ω $^{\leftarrow 13, 14}$].

(10) Now I'll do Gandlers. You $^{15\rightarrow}$have to tell the two M's from the B's. This is by cranial mound which is a bump on the head. The MI and BI have a single bump. The MII and BII have a double bump which $^{16\rightarrow}$shows they are very clever. So I means single, II means double $^{\leftarrow 15, 16}$.

(11) Now Plongers. $^{18\rightarrow}$There's an Ma and Mb and a Ba and Bb. $^{\leftarrow 18}$. Here we use two different tests. One of them we use again in a minute.

(12) Now $^{18\rightarrow}$the M-Plongers are distinguished by the vibratory sensor and you find that the M-Plonger-a has a fixed sensor^{+} (no sorry, retractible^{+}), whereas the

Mb is fixed $^{\leftarrow 18}$. Turn now to the B's^{20} $\rightarrow$. Here we find that one of them has a hairy dorsal mound. Hairiness is a good thing because it's an insulation against heat loss in digestion.

(13) The one with the hairy mound is B-Plonger-b $^{\leftarrow 20}$. Anyway that's the Plongers, [the prickers with 2 sprongs.] The last ones are the Gandleplongers.

(14) [As I said there are 2 sorts of α and Ω's. [$^{23\rightarrow}$The α's are Mα and Tα $^{\leftarrow 23}$.] That's all we need to know number of bodies and sprong type. Now $^{23\rightarrow}$we have one BΩ on its own. And two TΩ's $^{\leftarrow 23}$. There $^{24\rightarrow}$are Ωa and Ωb there we find a difference we used before. It's vibratory sensor and again its the a which is retractible. The b is fixed $^{\leftarrow 24}$ (That should do).

(ii) *Serialist with serialist programme*

(1) $^{1\rightarrow}$Zoologists have classified the Gandlemuller on the basis of physical characteristics $^{\leftarrow 2}$.

(2) $^{2\rightarrow}$The three main types are Gandlers, Plongers and Gandleplongers $^{\leftarrow 2}$. $^{3\rightarrow}$Gandlers have no sprongs. Plongers have two sprongs. Gandleplongers have one sprong $^{\leftarrow 3}$.

(3) $^{4\rightarrow}$There are four subdivisions of Gandler; MI, MII, BI and BII $^{\leftarrow 4}$ $^{5\rightarrow}$The M's have one body, the B's have two bodies. The MI and BI have a single cranial mound. The MII and BII have a double cranial mound. $^{\leftarrow 2}$.

(4) $^{6\rightarrow}$There is an M-Plonger-a and b and B-Plonger-a and b $^{\leftarrow 6}$ $^{7\rightarrow}$M's with one body and are distinguished by the type of vibratory sensor, which for M-Plonger-a is retractible. The b is fixed.

(5) The two B-Plongers have two bodies and are distinguished by type of dorsal mound. The B-Plonger-a has a smooth dorsal mound, the "b" has a hairy one $^{\leftarrow 7}$.

(6) (Let's see,) $^{8\rightarrow}$there are 2 Gandleplonger-α's and 3 Ω's $^{\leftarrow 8}$.

(7) $^{9\rightarrow}$The α's are the Mα and the Tα with one and three bodies respectively $^{\leftarrow 9}$.

(8) ^{10}The Ω's have one B and two T types, TΩa and TΩb $^{\leftarrow 10}$.

(9) (Oh) $^{8\rightarrow}$α's have a foresprong, Ω's have a tailsprong $^{\leftarrow 1}$ and $^{11\leftarrow}$the T-Gandleplonger Ωa has a retractible vibratory sensor whereas the b is fixed $^{\leftarrow 11}$.

(iii) *Holist with serialist programme*

(1) Now, $^{2\rightarrow}$there are 3 main types of $^{1\rightarrow}$Gandlemuller $^{\leftarrow 1}$. $^{4\rightarrow}$There are four called Gandlers^{4} $\leftarrow$, $^{6\rightarrow}$four called Plonger $^{\leftarrow 6}$ and $^{8\rightarrow}$5 called Gandleplonger^{8} $\leftarrow$. That's 13 altogether.

(2) The group of 5 come in two kinds α or Ω depending on a physical characteristic $^{\leftarrow 8}$ (Oh yes) $^{1\rightarrow}$Zoologists have made a classification based on physical $^{\leftarrow 1}$ characteristics.

(3) $^{2\rightarrow}$Some of them have spiky things, some don't $^{\leftarrow 2}$.

(4) Some have 1 body, some have 2 or 3.

(5) You also have various hairy or smooth, single or double mounds.

(6) There's something else. Retractible vibratory sensors, or fixed. That's used twice.

PAUSE

(7) (Let's see). $^{4\rightarrow}$There are 4 Gandlers, M and B $^{\leftarrow 4}$ $^{6\rightarrow}$4 Plongers M and B $^{\leftarrow 6}$ and $^{8\rightarrow}$5 Gandleplongers $^{\leftarrow 8}$ $^{9\rightarrow}$M & T of one sort $^{\leftarrow 9}$ and $^{10\rightarrow}$M and B of other $^{\leftarrow 10}$ (No, B and T^{+}) You $^{4\rightarrow}$tell the Gandlers apart by a suffix I or II $^{\leftarrow 4}$ telling you whether $^{5\rightarrow}$they have this mound single or double $^{\leftarrow 5}$.

(8) You tell $^{6,\,7\rightarrow}$Plongers apart by sensors, a fixed b retractible $^{\leftarrow 6,\,7}$ (It might be the wrong way there) (I think) $^{7\rightarrow}$you also get the mound in here. Hairy is b $^{\leftarrow 7}$.

(9) The $^{8\rightarrow}$Gandleplongers have a thing which is fore or aft. You put α or Ω after the name $^{\leftarrow 8}$.

(I've missed something, but I can't really remember all the bits. I got quite a lot though).

(iv) *Serialist with holist programme*

(1) In $^{1\rightarrow}$surveys of Mars, Zoologists have classified Gandlemullers into 13 subspecies depending on physical characteristics $^{\leftarrow 1}$.

(2) $^{2\rightarrow}$There are also differences in behavioural habits $^{\leftarrow 2}$.

(3) $^{3\rightarrow}$Gandle is mud. Muller is miller $^{\leftarrow 3}$.

(4) They $^{4\rightarrow}$have various physical things that are used . . . There are sprongs, foreplank and a ventral thing. Masticators, an aperture and a dorsal mound $^{\leftarrow 4}$.

PAUSE

(5) $^{6\rightarrow}$There are 3 main subspecies: M $^{5\rightarrow}$means mono, B means Bi and T means tri, for number of bodies $^{\leftarrow 5}$. The names are Gandler, Plonger and Gandleplonger $^{\leftarrow 6}$ $^{3\rightarrow}$They live in caves $^{\leftarrow 3}$

(6) $^{10\rightarrow}$Gandlers have no sprongs $^{\leftarrow 10}$ $^{11\rightarrow}$Plongers have 2 $^{\leftarrow 11}$ and $^{12\rightarrow}$Gandleplongers have 3 $^{\leftarrow 12}$.

(7) [$^{8\rightarrow}$They have masticators] for eating mud $^{\leftarrow 8}$ $^{9\rightarrow}$which takes 2½ minutes and is stored $^{\leftarrow 9}$.

(8) $^{10\rightarrow}$When Owzards, the Martian night vulture, attacks Gandlemullers, he lies flat excreting all mud $^{\leftarrow 10}$. (No, that's just Gandlers)$^{+}$ because $^{11\rightarrow}$Plongers prick or stab and jacknife $^{\leftarrow 11}$.

(9) Some have $^{12\rightarrow}$spoon-shaped masticators which are hairy or smooth $^{\leftarrow 12}$.

(10) You $^{15\rightarrow}$get M-Gandlers and B-Gandlers with suffix I and II meaning single or double cranial mound $^{\leftarrow 15}$.

(11) You get $^{18\rightarrow}$α or Ω meaning retractible or fixed sensor $^{\leftarrow 18}$. (I can't remember any more with much clarity). I know some of them $^{25\rightarrow}$swim in various ways $^{\leftarrow 25}$. And its a $^{20\rightarrow}$B-Plonger-b that has a hairy something $^{\leftarrow 20}$. And $^{24\rightarrow}$ there are TΩa's and b's depending on the number of spikes $^{\leftarrow 24}$.

The first analysis (Table 3), is a content analysis of the number of occurrences of:

(a) falsehoods;
(b) corrected falsehoods;
(c) inventions (items imported from outside the described universe);
(d) anticipatory statements about what is to come later;
(e) deductive statements;
(f) irrelevant statements (i.e. those that are irrelevant to the required body of knowledge;
(g) redundant statements (i.e. those that over-specify this body of knowledge);
(h) the total number of statements analysed for a given subject.

The second analysis (Table 4) is a teachback order analysis intended to show the extent to which a student's self-constructed teachback of the concepts he has learned departs from the order in which these concepts were presented by the teaching programme to which he was assigned. The tabulated numbers are frame numbers in the respective teaching programme, (holist or serialist). The order of the tabulated numbers is the sequence in which the pertinent concepts were evoked during teachback.

2.6 DISCUSSION OF THE NUMERICAL RESULTS

Scrutiny of Table 1 [Task (I) free learning data] indicates a clearcut distinction between serialists and holists in terms of "complex" or "large predicate" hypotheses. The distinction can be heightened by taking the nature of the hypotheses into account and, in this case, it is also evident that the *type* of single predicate hypotheses tested by the serialist differs from the *type* (of single or complex hypotheses) tested by the holist. There is also a positive correlation between success and the total number of hypotheses tested.

The same competence assignment can be made in terms of the Task (4) teachback data (Tables 3 and 4). In Table 3 (content analysis) holists are distinguished from serialists in terms of the number of inferential statements they produce where an inferential statement is *either* an *anticipatory* statement *or* a *deductive* statement. In Table 4 (teachback order analysis) it is possible to distinguish the serialist from the holist by a tendency, on the part of a serialist, to preserve the order of the programme presentation format which is absent in the holist. Presented with a holist programme the serialist is unable to preserve the complete order but he does manage to preserve

TABLE 3

Content analysis of teachback protocols (Task II)

	Subject No.	Falsehoods/corrected falsehoods	Inventions	Statements of information to come or delivered	Statements deduced	Irrelevant	Redundant	No. of statements—total (excludes interjections, repetition or corrections)			
Serialist with serialist programme	9	0	0	0	0	0	0	29	Serialist	Serialist material	Matched students
	8	1/1	0	0	0	0	0	28			
	16	1/1	1	1	1	0	0	41			
	3	1/0	0	3	1	0	0	47			
Holist with serialist programme	14	1/1	0	0	7	0	0	37	Holist		Mismatched students
	11	2/1	0	8	4	1	0	33			
	2	0	1	2	7	1	0	26			
	15	3/1	0	1	4	0	0	34			
Serialist with holist programme	1	2/0	0	1	0	11	2	39	Serialist	Holist material	
	12	3/1	0	0	0	7	0	28			
	6	4/1	0	0	0	14	3	42			
	1	6/0	1	0	1	20	4	48			
Holist with holist programme	5	0/0	1	5	3	9	0	66	Holist		
	9	1/1	1	12	5	5	0	70			
	7	1/1	2	13	1	23	3	110			
	13	2/1	6	17	10	23	24	116			

sequentially arranged fragments. So far as we know there is no generally accepted statistical test for similarity matching discrete patterns of variable length. Hence, no analysis is offered.

The gross data (test scores for holists and serialists, matched and mismatched) are shown in Table 2. First, it is quite evident, on examining the Task (II) test scores, that matched students learn more efficiently than mismatched students. Since the rankings do not overlap a statistical test is gratuitious but, as a formality, the difference between matched students

$N = 8$ and mismatched students $N = 8$ is significant (in favour of the matched group) at the 0·1 % level of significance ($0{\cdot}001 > P$) using the Mann-Whitney U-test. The same comments apply to an intergroup comparison of the ratios:

$$\frac{\text{Task (II) Test Score (Session II)}}{\text{Task (I) Test Score (Session I)}} \times 100\%$$

Comparing the ($N = 4$) mismatched holists with the ($N = 4$) mismatched serialists there is a difference in favour of the holists, at the 1 % level ($0{\cdot}01 > P$) which we believe to reflect the fact that an irredundant holist can (with difficulty) learn from a serialist programme. In fact, those mismatched

TABLE 4

Teachback order in relation to programme frame no.

	Subject No.	
Serialist with serialist programme	9	1→2→3→4→5→6→7→8→9→10→8→11
	8	1→2→3→4→5→6→7→6→7→8→9→10→11
	16	1→2→3→4→5→6→7→8→9→10→11
	3	1→2→3→4→5→6→7→8→9→10→11
Holist with serialist programme	14	2→1→4→6→8→1→2→4→6→8→9→10→4→5→$\substack{6\\7}$→8
	11	1→2→1→9→2→3→4→5→7→11→8→$\substack{9\\10}$→11
	2	1→2→4→6→8→2→8→2→3→8→1→7→5→7→4→6
	15	1→2→1→2→3→4→6→8→4→5→6→7→9→10→9→11
Serialist with holist programme	1	3→4→6→10→11→12→7→8→9→15→9→21→11→13→14→23→24→25
	12	1→2→3→8→4→5→6→10→11→12→13→8→15→16→18→20→24
	6	1→2→3→4→6→5→3→10→11→12→8→9→10→11→12→$\substack{15\\20}$→$\substack{18\\24}$→25
	4	1→3→5→4→$\substack{6\\12}$→11→15→16→20→9→16→18→11→13→14
Holist with holist programme	5	1→3→1→6→5→4→15→16→18→20→13→14→7→15→18→20→18→15→20→23→24→13→10→11→12→13→14→24
	9	1→2→1→5→7→8→10→11→12→$\substack{13\\14}$→5→15→18→22→18→20→23→22→24
	7	1→2→7→8→1→3→9→18→19→10→11→13→14→10→1→6→15→18→23→5→15→18→5→12→13→14→23→10→11→12→13→14→15→16→18→20→23→24
	13	1→6→5→7→8→10→3→7→11→12→6→5→15→18→10→15→4→16→15→10→16→15→6→18→20→22→19→23→12→13→14→23→5→24

subjects classified as irredundant holists learned the task after 4–7 repetitions of the serialist teaching programme, compared with the 1–3 repetitions required by (matched) serialists. As desired (condition 4 of section 2.1) there is no significant difference between the scores achieved by matched serialists and matched holists.

The influence of teachback on learning Task (I) is reflected in the test scores achieved for Task (I) at Session (II) [after the teachback experience of Session (I)]. Comparing the scores of the ($N = 8$) students receiving a real teachback experience (marked TB) with those of ($N = 8$) students receiving ineffective teachback there is, once again, no overlap in the ranking and the bias is strongly in favour of teachback.

The difference in question is significant at the 0·1% level ($0{\cdot}001 > P$) using the Mann-Whitney U-test.

2.7 PERIPHERAL RESULTS

From the theory, we predict a positive correlation between the number of *hypotheses* posed by a student and his efficiency. The appropriate figures to examine are "number of hypotheses per unit time", this point is supported by the data of Table 1.

Turning to Table 3, it is possible to distinguish between the effect on teachback of programme type (serialist/holist) and student competence (serialist/holist). Relative to a serialist programme, the holist programme injects either *irrelevant* or *redundant* statements into the teachback. Relative to a serialist student, a holist student is prone to make inferential statements. The holist comes into his own in the matched condition when he can *use* the irrelevant or redundant material provided by a holist programme in order to make *inferences*.

The teachback data of Table 4 deserves further scrutiny, since it might lead to a very objective method for assigning competence types. Given a serialist programme, the serialists show a remarkable tendency to preserve the concept (and frame) ordering. In contrast, the holists disrupt it quite effectively. It should be noted that holists have about the same disrespect for the ordering inherent in a holist programme. The weak point is the difficulty (without an appropriate matching test) of demonstrating that serialists *do* try to preserve the ordering of a holist programme, even though, almost by definition, their endeavours will be thwarted.

2.8 AUXILIARY STUDY

As noted in section 1.3 a subgroup of the competence assigned subjects learned the "operon" task, described in section 2.1 under matched and

TABLE 5

Test scores on auxiliary task ("System Learning")

Subject	Test score maximum =20		
10	20	Serialist subjects	Serialist programme
3	17		
6	18		
8	6		Holist programme
16	8		
4	10		
2	11	Holist subjects	Serialist programme
15	9		
14	13		
13	20		Holist programme
7	19		
11	19		

mismatched conditions (i.e. as before, using a teaching programme that did or did not suit their competence). No molecular data was collected but the molar results (test scores for a test administered after learning) are shown in Table 5.

Judging from this data, a competence assignment based on taxonomy learning may be extrapolated into the area of "system learning". If students are matched to their instruction, according to the original assignment, they learn effectively; if they are mismatched they fail to do so. There is enough circumstantial evidence for differences in the mechanism of "system learning" under matched and mismatched conditions to justify the collection and analysis of the molecular data required to support this point of view.

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